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Retrofit Energy Conservation in Residential Buildings in Southern California

Robert H. Turner
Gajanana C. Birur
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June 15, 1982

Prepared for
Southern California Edison Company
Through an Agreement with
National Aeronautics and Space Administration
by
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ABSTRACT

Rising energy costs have motivated many homeowners to utilize energy conservation techniques to reduce costs of heating and cooling their homes. The average homeowner requires guidelines in choosing the energy conservation techniques that will be cost-effective for the situation considered. This study considers the technical and economic performance of several energy conservation techniques that can be readily retrofitted into houses. Investments in the conservation techniques are compared to alternate investments that are available to the homeowner. The conditions for which the investments in the conservation techniques become attractive are identified.

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EXECUTIVE SUMMARY

As energy costs escalate, many homeowners are motivated to install energy conservation techniques (ECTs) to reduce costs of heating and cooling their homes. However, the average homeowner requires guidelines for when a candidate ECT is cost-effective and when it is not. This study considers the technical and economic performance of several common ECTs, all of which can be readily retrofitted into houses. Investments in ECTs are compared to alternative investments that the prudent homeowner might make, and the conditions are identified for which the ECT investments become attractive. Solar energy systems are not considered in this study.

There are three JPL memoranda[1] which augment and support this report. These are titled:

1. "Economic Payback Period and Figure of Merit Associated with Solar and other Energy Conservation Investments."

2. "Optimal Attic Insulation Thickness."

3. "An Evaluation of Selected Energy Conservation Techniques to Reduce Residential Summer Cooling Costs in Palm Springs."

Each of the three sub-studies is self-contained and investigates a particular area of interest. The first memorandum develops and illustrates the economic rating system used throughout the study.

The ECTs considered and their relative rankings are indicated in Table 1.

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[1]Copies of these memoranda may be obtained by contacting the authors.

Table 1. Ranking of Considered Energy Conservation Techniques

Rank	Energy Conservation Technique (ECT)	Comments
1	Insulate Bare Attic	Always recommended in every situation!
2	Weatherstrip	Always recommended in every situation!
3	Homemade Insulating Shutters	Good investment but can be a daily chore and requires fabrication by the homeowner
4	Insulate Floors by Homeowner	Good investment but requires a one-time strenuous effort by the homeowner
5	Insulate Stud Walls	Good long-term investment; also good in areas requiring summer air conditioning
6	Storm Windows over Single Pane	Not recommended in mild climates; good for cold climates
7	Insulating Thermal Shades	Not recommended in mild climates; good for cold climates, but requires daily chore
8	Decorator Insulating Shutters	Good only for cold climates; daily chore
9	Upgrade Attic Insulation from R-11 to R-30	Good only for cold climates
10	Insulate Floors by Contractor	Not generally recommended
11	Triple Pane Windows	Not generally recommended

SECTION I

INTRODUCTION

Although it is well known that conservation measures can be retrofit-installed into homes to reduce energy consumption and save money, most homeowners do not have a feel for which available energy conservation techniques (ECTs) are most cost effective; nor, when presented with several alternatives, are they able to rank their candidate ECTs in order of economic attractiveness so that the greatest return is received on money spent. Furthermore, items that may be economically attractive in one climate may not be as useful in another location. Finally, when compared against alternative long-term investments into which the prudent homeowner could venture his money, the homeowner may feel uncomfortable in making a decision.

This study surveys the common ECTs that can be retrofit-installed into residential buildings. The quantity of saved energy for heating and cooling attributable to each ECT is evaluated for three common modes of heating: natural gas heating at 60¢/therm; heating via heat pump at $1.20/therm; and electric resistance heating at $2.40/therm (electricity cost = 8.2¢/kWh). 1 therm = 100,000 Btu. Energy conservation to reduce air-conditioning bills is also considered for hot desert climates. In every case, a life-cycle cost comparison is made between the long-term revenue due to energy conservation and a safe and conventional alternative investment that might be available to the prudent homeowner. The comparison between investment in an ECT and the alternative investment is brought into clear perspective using the life-cycle payback period (N) and an economic Figure of Merit (FOM). The FOM allows for relative ranking between candidate ECTs. Because the entire spectrum of winter heating climates in California is surveyed, the decision maker can determine whether or not a considered ECT is recommended in a given climate, and under what conditions an ECT investment becomes attractive.

Although this report is central to this study, there are three other less formal memoranda[1] which augment and support this report. These are titled:

(1) "Economic Payback Period and Figure of Merit Associated with Solar and Other Energy Conservation Investments."

(2) "Optimal Attic Insulation Thickness."

(3) "An Evaluation of Selected Energy Conservation Techniques to Reduce Residential Summer Cooling Costs in Palm Springs."

Each of the above sub-studies is self-contained and presents its own statement, analysis and conclusions. The first memorandum ("Economic Payback...") develops and discusses the life-cycle economic comparison parameters that are the foundation of this study. Because this study shows that one of the most effective ECTs that can be installed is attic insulation in houses with bare attics, "Optimum Attic Insulation Thickness" analyzes and determines the attic insulation

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[1]Copies of these memoranda may be obtained by contacting the authors.

thickness consistent with maximizing the ECT investment. The analysis shows that in a hot desert climate where air-conditioners are commonly used to provide comfort conditioning throughout the summer, insulation thicknesses are warranted that are far in excess of the California insulation code for new construction houses. A general algorithm is given to assess the optimum insulation thickness for any climate and energy cost conditions. The third memorandum ("...Summer Cooling in Palm Springs") is a detailed case study of ECT cost effectiveness for reducing the summer air-conditioning load in a severe Southern California desert climate.

A companion JPL report titled "Retrofit Energy Conservation and Solar Energy in Residential Buildings on Santa Catalina Island," dated January 1982, is an in-depth case study applying the results and methods developed in this study. Catalina Island features a mild but long winter climate, with no requirement for summer cooling, and abnormally high energy costs due to the remoteness of the island.

SECTION II

DESCRIPTION OF ENERGY CONSERVATION TECHNIQUES

The following energy conservation techniques (ECTs), all of which can be readily retrofitted into normal homes, have been selected for evaluation:

(1) Insulation of attics.
(2) Insulation of walls.
(3) Insulation of wooden floors.
(4) Weatherstripping.
(5) Double or triple pane windows.
(6) Thermal curtains and shades.
(7) Movable insulating window shutters.
(8) Decorator insulating window shutters.

The pertinent technical information for the above ECTs are taken from the technical literature, a review of which is found in the bibliography. The cost of the items is taken from a survey of Southern California sources and also from the literature. The description of each item is omitted here as redundant; however, there is a large amount of information available to the reader in the bibliography.

(1) Attic Insulation: Due to the difficulty of retrofit-placing insulation batts in the low angle roofs characteristic of Southern California, cellulose is normally blown into attic spaces. For new construction residential buildings the State of California Title 24 Code stipulates the following attic resistance values:

$$R = \begin{cases} 20, & \text{DD (degree day)} < 3000\ ^\circ\text{F-day/year} \\ 12.7 + 2.43*\text{DD}/1000, & \text{DD (degree day)} > 3000\ ^\circ\text{F-day/year} \end{cases}$$

The companion memorandum to this report, titled "Optimum Attic Insulation Thickness," shows in some areas it is cost-effective to exceed the Title 24 requirement, especially in hot climates where air-conditioners are commonly used throughout the summer. However, to facilitate comparisons for a retrofit insulation into bare attic situation, it will be assumed that R-19 is added in every case. Without insulation, the thermal resistance of an attic is taken from the ASHRAE Handbook of Fundamentals (1981) to be $R_O = 3$. With the addition of R-19, the improved attic insulation is $R_{ECT} = 22$. A telephone survey reveals that this insulation (5-1/2 inches of blown cellulose) costs $S = 30¢/ft^2$.

Because retrofit insulation of an attic is a relatively simple and effective ECT to apply, it is possible that upgrading a small amount of insulation would be cost-effective in some cases. Thus, we shall also consider the case where a house already has minimal insulation of R-11 value, so the total attic thermal resistance value is $R_O = 14$. Adding R-19 to the existing insulation would increase the overall insulation value to R-33, and cost $S = 30¢/ft^2$.

(2) Stud Wall Insulation: Because many older buildings in California a do not have insulation in the walls, this represents another possible area where an ECT could be retrofitted to save energy and possibly money. The telephone survey reveals that the cost to fill a 2 x 4 stud wall cavity with blown cellulose insulation is around S = \$0.60/ft^2, and this will increase the wall resistance from R_0 = 4 to R_{ECT} = 13.

(3) Insulation of Wooden Floors: Heat loss through the floor is serious from the standpoint of two criteria. First, the value of the heat itself is important, and secondly most people with cold feet will feel uncomfortable even if air and surrounding temperatures are otherwise acceptable. Thus, with cold floors, people are more likely to turn up the thermostat, increasing heat losses through the walls, windows and via infiltration. One way to reduce floor loss and increase comfort in a house with wooden floors on concrete foundations is to insulate the floor. This can be a somewhat difficult, dirty and slow job in many cases where normal crawl spaces result in an unhandy access. Most insulation contractors contacted indicated that they had never had a request for such a job, and therefore had little experience in bidding a retrofit floor insulation job; on being pressed for an estimate, the consensus was around \$1/ft^2, which included labor and materials and overhead. The cost of the materials is around \$0.20/ft^2 for the R-11 insulation batts, wire, staples and staple gun, et cetera. The insulation will increase the floor and crawl space thermal resistance value from R_0 = 6 to R = 17. Thus, the retrofit floor insulation situation is

$$R_0 = 6 \text{ h-ft}^2 - {}^\circ\text{F/Btu:} \qquad R_{ECT} = 17$$

$$\text{Cost, } S = \begin{cases} \$0.20/\text{ft}^2 \text{ if installed by homeowner} \\ \$1.00/\text{ft}^2 \text{ if installed by contractor} \end{cases}$$

(4) Weatnerstripping: Whereas all of the other ECTs considered in this report reduce heat gain or loss by conduction through the building skin, and hence are subject to fairly reliable calculation techniques, infiltration reduction is more difficult to quantify. Most average houses in Southern California have a higher infiltration rate than houses in other parts of the country due to the warmer weather and the fact that until recently people were not interested in spending a little more money to make a house airtight to reduce energy consumption. The amount of air change from the house to the outside depends on many factors, including the area and kind of windows, number of doors, number and kind of fireplaces, type and quality of construction, prevailing climate and wind conditions, practices of the occupants, et cetera. Baring obvious construction oversights or maintenance requirements, the main sources of infiltration are cracks around window frames and doors, spaces between doors and floors, leaky fireplace dampers, and drafty sockets. Other air leaks can sometimes be isolated by the owner in specific instances. The State of California Title 24 requirement specifies a goal of 1 house air volume

change per hour (1 AC/h) for a new construction house. Most existing houses built prior to 1975 can be characterized by 1.5 AC/h or 2 AC/h, and in some cases even more. By applying weatherstripping to windows and doors, caulking frames and sills, and generally identifying and plugging up leaks, the homeowner can often reduce the infiltration rate by 0.5 to 1 AC/h. This is generally done by the homeowner himself and usually requires no special tools or skill, and the materials are available from most hardware stores. Many pamphlets, articles and other reference materials are available for the handyman describing how to install weatherstripping materials. Because air leakage can be the most severe single source of winter heat loss, it is vital that these losses be minimized.

In evaluating the cost of weatherstripping for houses of different sizes, it appears that a good rule for costing retrofit weatherstripping is

$$S = \$0.10/ft^2$$

where S is the initial cost per square foot house floor area. Thus, it would cost $200 to weatherstrip a 2000 square foot house. One of the problems with such weatherstrip retrofit compared to other ECT installation is the unpredictability of resulting performance or even the need for renewed weatherstripping on a given door or window. Also, it involves the time of the homeowner.

(5) <u>Double Pane Windows</u>: Because the window area on a house has a much higher heat transmission capability than a normal wall or ceiling, a relatively small window area can lose as much heat as a larger wall space. There are several possible techniques to reduce this loss, including shutters, curtains, and extra transparent glazings. All are considered in this study. Placing an additional pane of glass over a window or sliding glass door allows the occupant to retain the view, but reduces heat loss. In cold areas of California, double pane windows are mandated for new construction buildings. This study examined the economics of adding a second pane of glass to a single pane window; or a third pane to a double pane window in cold climates. In some areas this second pane is added in the autumn and removed at the end of winter, and the second window is called a "storm window." The storm window can actually have a double benefit; namely it directly reduces heat loss through the window and it can also reduce infiltration. In this study it will be assumed that weatherstripping is already applied, so the only calculated benefit will accrue from the increase in thermal resistance through the window. The ASHRAE Handbook of Fundamentals (1981) states that the window winter condition thermal resistances are

Window Type	Thermal Resistance
Single Pane Window	: R = 0.90 h-ft^2-°F/Btu
Single Pane with Storm Window	: R = 2.00 " " " "
Double pane with Storm Window	: R = 3.00 " " " "

The addition of the extra window pane costs around $3.00 per square foot, and the performance improvement is indicated above.

(6) Thermal Curtains and Shades: Decorator pulldown shades with expandable strips of insulation and reflective internal coatings are commercially available. Generally, the edge of the shade is held by a track to prevent infiltration bypass, and the bottom is weighted so when drawn the shade makes a relatively airtight plenum with the window. When the shade is rolled up it is hidden by a valance. When such a shade is drawn it will increase the overall thermal resistance through a single pane window from R = 0.9 to R = 4 h-ft^2-°F/Btu. The cost of these kind of shades is around $4.50/ft^2 of window surface area. The estimated lifetime is 12.5 years.

(7) Movable Insulating Window Shutters: An inexpensive and effective window shutter that the homeowner can make himself is a simple piece of lightweight polystyrene insulation cut to fit the window cavity. The side facing the living space has cloth or a picture of the builder's choice, and the exterior side can have reflective film. Small magnets are glued to the window or sill, and these hold steel strips that are attached at appropriate locations to the outside of the shutter; one entrepreneur selling magnet strips calls the system "nightwall." The homeowner deploys the shutter at night and takes it down in the morning to allow light and view into the room. A disadvantage is the daily chore and the necessity of storing the piece when it is down. Such a unit will increase the overall window thermal resistance from R = .9 to R = 6. The homemade cost is estimated at $1.50/ft^2, which is the cost of materials, as the labor is free. The estimated lifetime is 7 years.

(8) Decorator Insulating Window Shutters: Part of the difficulty with the daily-deployable shutter described as Item 7 is the necessity of making the piece, and part is the requirement that when the unit is off it must be stored away, perhaps behind a couch or in a closet. To overcome these objections, there are commercially available hinged shutters that swing out from a wall to close and swing back on to the wall to open. These have insulation in the interior and weather-stripping felt to secure a tight seal. They are generally well built and have high aesthetic value. They increase the overall window thermal resistance from R = 0.9 to R = 6, and with care should last for 25 years. They cost from $6/ft^2 up; $6/ft^2 will be used in this analysis.

The engineering and economic factors described above for the considered ECTs, and which will be used in this analysis, are summarized in Table 2-1.

Table 2-1. Engineering And Economic Factors Of Various ECTS

Item	House Element/ Considered ECT	Thermal Resistance Value, h-ft^2-°F/Btu: Base Case Without ECT	Thermal Resistance Value, h-ft^2-°F/Btu: Base Case With ECT	ECT Useful Lifetime L, years	Cost of ECT, \$/ft^2	Comments
1	Attic Insulation	3 14	22 33	25 25	0.30 0.30	Initial base attic upgrade minimal insulation
2	Wall Insulation	4	13	25	0.60	
3	Floor Insulation	4	13	25	0.20 1.00	Owner-installed Contractor-installed
4	Weatherstripping[a]	1.5 AC/h	1.0 AC/h	12.5	0.10	
5	Double Pane Windows	0.9	2.0	12.5	3.00	
	Add Pane to Double Pane Window	2.0	3.0	12.5	3.00	
6	Insulating Window Shades	0.9	4	12.5	4.50	
7	Movable Insulating Window Shutters	0.9	6	7	1.50	Owner-fabricated from hardware stormaterials; task required
8	Decorator Insulating Window Shutters	0.9	6	25	6.00	

[a]Weatherstripping contribution is measured in reduction of house air volume changes per hour.

SECTION III

ECONOMIC EVALUATION OF THE ENERGY CONSERVATION TECHNIQUES

In the companion supporting memorandum to this report, titled "Economic Payback Period and Figure of Merit Associated with Solar and Other Energy Conservation Investments," an algorithm is derived, described, and illustrated that allows life-cycle economic evaluation of a given ECT relative to an alternative investment. A complete description and illustration is also described in the companion report regarding energy conservation on Catalina Island. Therefore, only the basic equations required for the analysis will be presented here without formal description.

First it is necessary to estimate the quantity of heat saved each winter and/or summer attributable to the ECT. Then this value is multiplied by the cost of heat to estimate the annual money saved due to installation of the ECT, this annual money savings is R ($/year-ft^2). In the case where summer cooling is standard practice, the contribution made by the ECT to lowering the air-conditioning bill should be assessed and added to the winter contribution. Dividing the initial cost of the ECT, S ($/ft^2), by R gives the simple payback period, S/R, or

$$\text{Simple Payback Period} = S/R \text{ (years)} \qquad (3\text{-}1)$$

Although the simple payback period is of interest, it does not take into account parameters as time value of money (i) and energy cost escalation (j). The derived equation, which does account for these parameters is

$$N = \frac{\ln\left[1 + \frac{S}{R}(j - i)\right]}{\ln \frac{1 + j}{1 + i}} \qquad \text{for } j > i \qquad (3\text{-}2)$$

where

N = life-cycle payback period (years)

S/R = simple payback period (years)

i = effective after-tax interest rate at which the homeowner can earn on his money, or the after-tax interest rate that the homeowner must pay to borrow money to install the ECT (i = %/year, a decimal)

j = energy cost escalation factor, the rate at which energy cost is increasing each year (j = %/year, a decimal)

In this study, it is assumed that the homeowner-investor can safely earn 10%/year on his money after taxes, or conversely, if he borrows money to make the home improvement, then the effective after-tax interest rate is 10%/year. Thus, $i = 0.10$. The annual rate of energy cost increase normally leads inflation by a few percentage points. In the past 10 years, the value of j has averaged around 14% per year, and there is no sign that this condition will abate. Therefore, in this study $j = 0.14$. Although it is not known what i and j will be years into the future, examination of equations 3-2 and 3-3 reveal that the relative differences and ratios of the two are more important than the absolute values, and, as j can be expected to be somewhat higher than i, exact precision is not required. The final results are similar for different relative values of i and j.

The economic Figure of Merit (FOM) has been derived to be

$$FOM = \left[\frac{\left[\frac{1+j}{1+i}\right]^L - 1}{\frac{S}{R}(j-i)} \right] - 1 \qquad (\text{for } j \neq i) \qquad (3\text{-}3)$$

where L is the considered economic lifetime of the ECT. The FOM relates the relative financial position of the ECT investor to his position had he made an alternative compound interest bearing investment paying interest rate i. The money saved each year by the ECT is assumed to be invested at interest rate i. In this way, a true life-cycle comparison between the investment in an ECT and an alternative investment can be made. If the FOM is zero at the end of a considered period L, then the investor breaks even. If FOM is negative, then the ECT should not be installed (from economic grounds) and the alternative investment is economically preferable. If the FOM is positive, then the ECT investment is preferable to the alternative investment over the considered investment period L. N, given by equation 3-2, is the life-cycle breakeven period where the future value of each investment is equal.

Two values of L are used in the calculations, (1) the expected lifetime of the ECT, and (2) 7 years. Energy conservation improvements into a home must be considered as a long-range investment, lasting the lifetime of the ECT. However, because Americans are a mobile people, a homeowner installing insulation into the attic, which can be expected to have a useful lifetime of at least L=25 years, may not be content to evaluate the investment over this period. Therefore, the calculations are also made for an L = 7-year period, in addition to the expected lifetime. The beneficial possibility that the homeowner may receive more money for his house when he sells it is not considered, nor is the adverse possibility that the property will increase in value sufficiently that the tax assessor will raise taxes on the property.

A sample calculation demonstrates how the calculations summarized in the tables to follow were generated. Consider the energy and money saved by retrofit insulation installation into a previously uninsulated attic. The initial or base value of thermal resistance from the house through the attic to the ambient

weather is R_o = 3 h-ft^2°F/Btu. After installation of the R-19 insulation into the attic space the new thermal resistance value is R-22. The cost of this installation is S = \$0.30/ft^2, and the life expectancy of the investment is L = 25 years. Consider a climate featuring 3000 degree-days (DD) of heating and 1750 DD of cooling, which typifys the high desert areas of California (e.g., Palmdale, Californa). The annual winter heat saved is

$$Q_s = \left[24\ \frac{h}{day}\right](DD)\left[\frac{1}{R_o} - \frac{1}{R_{ECT}}\right] \tag{3-4}$$

so

$$Q_s = \left[24\ \frac{h}{day}\right] 3000\ \frac{F\text{-}day}{year}\ \left[\frac{1}{3} - \frac{1}{22}\right] \frac{Btu}{h\text{-}ft^2\,°F}$$

$$Q_s = 20{,}727\ Btu/year\text{-}ft^2$$

$$= 0.207\ therm/year\text{-}ft^2$$

If the house is heated using a heat pump which has a winter average coefficient of performance (COP) of 2, and electricity cost is 8.2¢/kWh (which is the present cost of electricity in Southern California), then the first year money saved in winter due to the insulation ECT is

$$R = \frac{(\$0.0082/kWh)(20{,}727\ Btu/year\text{-}ft^2)}{(2.0)\ 3414\ \frac{Btu}{kWh}}$$

R = \$0.249/year-ft^2; money saved the first winter

The installation cost of the attic insulation is S = \$0.30/ft^2, so from equation 3-1, the simple payback period is S/R.

$$S/R = (\$0.30/ft^2)\ /\ (0.249/year\text{-}ft^2) = 1.21\ years$$

In this report j = 0.14 and i = 0.10 will be used as representative values of energy cost escalation factor and interest rate respectively. Then using these values in equation 3-2, we get 1.32 years for the life-cycle payback (breakeven) period to years (N = 1.32). The economic Figure of Merit (FOM) of the ECT relative to an alternative investment paying 10%/year for the considered economic life of the ECT is determined from equation 3-3. If

L = 7 years, then FOM = 4.89

L = 25 years, then FOM = 28.89

These values are reported in Table 3-1. Because FOM = 0 represents a breakeven value for the considered time period, and FOM = 1 represents a 100% better financial position for the ECT than the alternative investment after the considered time period, a FOM = 4.89 after 7 years represents a fantastic investment opportunity. The interpretation is that it is economically attractive to insulate the bare attic of a house if it is being heated with a heat pump in a moderately cold climate (3000 DD of heating requirement). Note that a negative FOM indicates that the ECT is not financially attractive compared to the considered alternative investment.

The summer calculation proceeds in a similar manner. For 1750 cooling degree days per summer, using equation 3-4 gives the heat load reduction Q_s = 12,091 Btu/ft^2-year. The cost to remove this heat (i.e., money saved) using an air-conditioner with summer average COP = 2.7 (Energy Efficiency Ratio, EER = 9.2) is

$$R = \frac{(\$0.082/\text{kWh})\ (12{,}091\ \text{Btu/ft}^2\text{-year})}{(2.7)\ (3414\ \text{Btu/kWh})} = \$0.107/\text{ft}^2\text{-year}$$

which is the money saved the first summer. The summer simple payback period is S/R = (0.30/0.107) = 2.79 years, the life-cycle payback period is N = 2.96 years, and

$$\text{FOM} = 1.55 \text{ for } L = 7 \text{ years}$$

$$\text{FOM} = 12.9 \text{ for } L = 25 \text{ years}$$

These values can be estimated by interpolation from Table 3-12. The resulting FOM indicates that retrofit attic insulation is a good conservation investment for summer savings where air-conditioners are used.

For the considered case the total money saved the first year, estimated by adding both the winter and summer money saved, is

$$R = 0.249 + 0.107 = \$0.356/\text{year-ft}^2$$

for which

$$S/R = 0.30/0.356 = 0.84 \text{ year}$$

is the simple payback period; less than a year!

$$\text{FOM} = 7.45 \text{ for } L=7 \text{ years}$$

$$\text{FOM} = 41.9 \text{ for } L=25 \text{ years}$$

Thus, in areas where air-conditioners are common practice to provide summer comfort, both summer and winter energy and money saving should be used to determine the economic appropriateness of retrofit ECT installation. Summer benefits of shades, double pane windows, shutters, et cetera, are considered in detail in the supporting memorandum to this report dealing with summer cooling costs in Palm Springs, and insulation and weatherstripping summer

impact will be only briefly considered here.

The ECTs described in Section II and summarized in Table 2-1 are evaluated for three modes of winter heating. These three modes of heating are the following:

(1) Natural Gas; $0.60/therm

(2) Heat Pump (COP = 2); 4.1¢/kWh = $1.20/therm

(3) Electric Resistance; 8.2¢/kWh = $2.40/therm

In each case, the FOM calculation is made for two time periods: (1) the economic ECT lifetime, and (2) 7 years. In every case $i = 0.10$ and $j = 0.14$, although if $i = 0.08$ and $j = 0.12$ had been used, then the results and conclusions would have been the same. The calculations are made for different winter conditions ranging from a climate characterized by 1000 degree-days to a climate of 10,000 DD. A winter climate of 1000 DD is extremely mild; the warmest parts of California have a winter climate a little in excess of 1000 DD. 10,000 DD of winter heating is an extremely severe climate, as might be characterized by the coldest place along the U.S.-Canada border. A good reference for estimating how many winter heating and summer cooling degree-days characterize a given California location is the California Solar Data Manual (1978). A list of typical California locations and their heating and cooling degree days is given below.

Location	DD_W (Heating)	DD_S (Cooling)
Santa Monica	1901	452 = 0[a]
Pasadena	1694	1187
Palm Springs	1240	3681
Palmdale	2929	1724
Death Valley	1205	5409
San Fernando	1800	1310
Lake Arrowhead	5200	415 = 0[a]
Bishop	4313	1037
Bakersfield	2185	2179

[a] Residential air-conditioning is not common practice in areas with DD_S less than 1000°F-day/year.

The conclusions relating to ECT economic effectiveness are determined by inspection of the Section III tables. Tables 3-1 and 3-12 reveal that retrofit installation of insulation is an economically attractive investment anywhere in California regardless of the mode of heating. However, if a small amount of insulation (R-11) is already present in the attic, then Table 3-2 indicates that the homeowner heating with gas who hopes for a payback within 7 years should not upgrade the insulation value to R-30, although the maintaining of a house with electric resistance heating would find the investment to be attractive in a cold climate, or for a long timeframe (i.e. L = 25 years). Table 3-13 shows that the short payback timeframe (L = 7 years) cannot justify the attic insulation upgrade from summer energy savings, although in hot climates (i.e., Palm Springs with 3600 DD summer cooling) the upgrade is attractive over the expected life of the insulation (i.e., L = 25 years).

The benefits of retrofit installation of insulation in 2 x 4 stud walls are considered in Table 3-3 for winter and Table 3-14 for summer. The benefits are long-term only for a natural gas house in a mild climate (i.e., Los Angeles with 1500 DD heating), but a good investment for an electric resistance home.

In a mild winter climate with requirement for summer air-conditioning, the combined summer and winter energy and money savings must be calculated for the retrofit stud wall insulation case, because either winter or summer savings by themselves appear to be somewhat marginal when a 7-year economic period is considered. Table 3-16 shows the overall annual benefit of wall insulation in a desert climate for a house heated in winter by a heat pump with COP = 2, and cooled in summer by an air-conditioner with COP = 2.7 (EER = 9.2); electricity cost = 8.2¢/kWh. In each box in Table 3-16, the number in parentheses is the simple payback period, S/R, for both combined winter and summer money savings; the second number is the economic Figure of Merit (FOM). Note that in all areas where air conditioning is practiced and a heat pump provides winter heating, retrofit installation of insulation into stud walls is a good intermediate term (7 years) investment. Naturally, for electric resistance winter heating the investment becomes even better. Note for mild winter climates and moderate summer climates the FOM for insulation in either case considered alone is negative or marginally positive (Tables 3-3 and 3-14), whereas for the combined case (Table 3-16) the FOM indicator is strongly positive, indicating a favorable investment. Such a table for combined winter and summer performance is not necessary for attic insulation because it can be justified by either winter or summer savings alone.

Floor insulation is a good investment if the homeowner installs the insulation himself (free labor, Table 3-4), but must be considered a much less attractive long-term investment if a commercial contractor makes the installation (Table 3-5). Insulating the floor is probably a summer disbenefit because the crawl space underneath the house generally is much cooler than the ambient air.

Weatherstripping is one of the best investments possible in all climates (Tables 3-6 and 3-15) when installed by the homeowner. This is especially true if the resident is aware of a certain door or window or other source of infiltration that will yield to weatherstripping. The air volume loss reduction in Tables 3-6 and 3-15 is only 1/2 house volume per hour. In some cases it is possible to reduce the infiltration by much more than 1/2 AC/h, in which case the FOM is much higher than shown here.

Applying storm windows is not economically attractive in mild climates with natural gas heating (Table 3-7). However, in even moderately cold climates (say 3000 DD of winter heating requirement) storm windows are attractive for houses with electric resistance heating. For colder areas than 3000 DD, the second glass pane is cost-effective even with heat pump heating. However, in cold areas (greater than 5000 DD) adding a storm window to a double pane window (making it a triple pane) is only recommended as a long-term investment (12.5 years) in cases of electric resistance heating, see Table 3-8. For gas heating, the third pane is not cost-effective.

Commercially available insulating curtains and shades are effective in cool to cold climates with electric heating, although they represent an ECT with which the homeowner must continually interact. The Palm Springs companion memorandum to this report indicates that in severe desert summer climates such curtains on east or west windows can be cost-effective if they reflect most of the sunlight that otherwise would have entered the room.

Due to the low cost and technical effectiveness of the homemade insulating window shutter, it is cost-effective in nearly all climates regardless of the heating mode (Table 3-10). In the milder winter desert climates it can also be good as a summer ECT, especially on east and west facing windows or sliding glass doors (see the Palm Springs memorandum).

Commercially available decorator window shutters are not nearly as cost-effective as the homemade window shutters, although they can still represent a good investment in all electric houses in cold climates (Table 3-11).

Note that certain ECTs considered above work in parallel, sich as insulation of ceiling and walls. The contributions made by parallel ECTs are additive because they do not generally impact on the performance of each other. However, the different techniques considered for reducing heat loss (or summer heat gain) through windows and sliding glass doors work in series with each other. For example, if storm windows and insulating shutters are used simultaneously, then each will reduce part of the total heat loss, detracting from the contribution that the other can make. Because there is only so much heat loss through a given window, parallel window ECTs would have to be evaluated together to determine if the combination is still cost-effective (assuming that each alone was!).

Table 3-1. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Attic Insul. R-19 in Base Attic   Cost of ECT, S = \$ .30 /ft^2 R_o = 3 h-ft^2-°F/Btu

ECT Lifetime L = 25 years; Considered economic life = 7 years. R_{ECT} = 22 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_s Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	6909	7.24	7.12	3.98	-.02	3.62	3.78	8.96	.96	1.81	1.96	18.93	2.92
2000	13818	3.62	3.78	8.96	.96	1.81	1.96	18.93	2.92	.90	1.00	38.85	6.85
3000	20727	2.41	2.58	13.95	1.94	1.21	1.32	28.89	4.89	.60	.67	58.78	10.77
4000	27636	1.81	1.96	18.93	2.92	.90	1.00	38.85	6.85	.45	.50	78.71	14.70
5000	34545	1.45	1.58	23.91	3.91	.72	.80	48.82	8.81	.36	.40	98.64	18.62
6000	41454	1.21	1.32	28.89	4.89	.60	.67	58.78	10.77	.30	.34	118.56	22.55
7000	48363	1.03	1.13	33.87	5.[illegible]7	.52	.57	68.75	12.74	.26	.29	138.49	26.47
8000	55272	.90	1.00	38.85	6.85	.45	.50	78.71	14.70	.23	.25	158.42	30.40
9000	62181	.80	.89	43.84	7.83	.40	.45	88.67	16.66	.20	.22	178.35	34.32
10,000	69090	.72	.80	48.82	8.81	.36	.40	98.64	18.62	.18	.20	198.27	38.25

Table 3-2. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Attic Insul. upgrade from R-11 to R-30; Cost of ECT, S = \$.30 /ft^2 R_o = 14 h-ft^2-°F/Btu

ECT Lifetime L = 25 years; Considered economic life = 7 years. R_{ECT} = 33 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/years-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	987	50.66	31.01	-.29	-.86	25.33	19.59	.42	-.72	12.66	11.48	1.85	-.44
2000	1974	25.33	19.59	.42	-.72	12.66	11.48	1.85	-.44	6.33	6.32	4.69	.12
3000	2961	16.89	14.45	1.14	-.58	8.44	8.15	3.27	-.16	4.22	4.37	7.54	.68
4000	3948	12.66	11.48	1.85	-.44	6.33	6.32	4.69	.12	3.17	3.34	10.39	1.24
5000	4935	10.13	9.53	2.56	-.30	5.07	5.17	6.12	.40	2.53	2.70	13.23	1.80
6000	5922	8.44	8.15	3.27	-.16	4.22	4.37	7.54	.68	2.11	2.27	16.08	2.36
7000	6909	7.24	7.12	3.98	-.02	3.62	3.78	8.96	.96	1.81	1.96	18.93	2.92
8000	7896	6.33	6.32	4.96	.12	3.17	3.34	10.39	1.24	1.58	1.72	21.77	3.49
9000	8883	5.63	5.69	5.41	.26	2.81	2.99	11.81	1.52	1.41	1.53	24.62	4.05
10,000	9870	5.07	5.17	6.12	.40	2.53	2.70	13.23	1.80	1.27	1.38	27.47	4.61

Table 3-3. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Wall Insul. in 2 x 4 Stud Walls   Cost of ECT, S = \$ .60 /ft^2 R_o = 4 h-ft^2-°F/Btu

ECT Lifetime L = 25 years;   Considered economic life = 7 years. R_{ECT} = 13 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	4153	24.07	18.88	.50	-.71	12.04	11.01	2.00	-.41	6.02	6.04	4.99	.18
2000	8307	12.04	11.01	2.00	-.41	6.02	6.04	4.99	.18	3.01	3.18	10.98	1.36
3000	12461	8.02	7.79	3.49	-.12	4.01	4.17	7.99	.77	2.01	2.16	16.97	2.54
4000	16615	6.02	6.04	4.99	.18	3.01	3.18	10.98	1.36	1.50	1.64	22.96	3.72
5000	20769	4.81	4.93	6.49	.47	2.41	2.57	13.98	1.95	1.20	1.32	28.95	4.90
6000	24923	4.01	4.17	7.99	.77	2.01	2.16	16.97	2.54	1.00	1.10	34.94	8.08
7000	29076	3.44	3.61	9.48	1.06	1.72	1.86	19.97	3.13	.86	.95	40.93	7.26
8000	33230	3.01	3.18	10.98	1.36	1.50	1.64	22.96	3.72	.75	.83	46.92	8.44
9000	37384	2.67	2.85	12.48	1.65	1.34	1.46	25.96	4.31	.67	.74	52.91	9.62
10,000	41538	2.41	2.57	13.98	1.95	1.20	1.32	28.95	4.90	.60	.67	58.90	10.80

Table 3-4. Technical and Economic Performance of ECT in Different Heating Climates

Homeowner Installed

ECT: Insulation of Wooden Floors   Cost of ECT, S = \$.20 /ft^2 R_o = 6 h-ft^2-°F/Btu

ECT Lifetime L = 25 years;   Considered economic life = 7 years. R_{ECT} = 17 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	2588	12.88	11.63	1.80	-.45	6.44	6.42	4.6	.10	3.22	3.39	10.2	1.21
2000	5176	6.44	6.42	4.60	.10	3.22	3.39	10.2	1.21	1.61	1.75	21.4	3.41
3000	7764	4.29	4.44	7.40	.65	2.15	2.31	15.8	2.31	1.07	1.18	32.59	5.62
4000	10352	3.22	3.39	10.20	1.21	1.61	1.75	21.4	3.41	.80	.89	43.79	7.82
5000	12941	2.58	2.75	13.00	1.76	1.29	1.41	26.99	4.51	.64	.71	54.99	10.03
6000	15529	2.15	2.31	15.80	2.31	1.07	1.18	32.59	5.62	.54	.59	66.19	12.23
7000	18117	1.84	1.99	18.60	2.86	.92	1.01	38.19	6.72	.46	.51	77.38	14.44
8000	20705	1.61	1.75	21.40	3.41	.80	.89	43.79	7.82	.40	.45	88.58	16.64
9000	23294	1.43	1.56	24.19	3.96	.72	.79	49.39	8.92	.36	.40	99.78	18.85
10,000	25882	1.29	1.41	26.99	4.51	.64	.71	54.99	10.03	.32	.36	110.98	21.05

Table 3-5. Technical and Economic Performance of ECT in Different Heating Climates

Contractor Installed -
ECT: Insulation of Wooden Floors — Cost of ECT, S = \$1.00 /ft^2 — R_o = 6 h-ft^2-°F/Btu

ECT Lifetime L = 25 years; Considered economic life = 7 years. — R_{ECT} = 17 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	2588	64.39	35.68	-.44	-.89	32.2	23.17	.12	-.78	16.1	13.92	1.24	-.56
2000	5176	32.20	23.17	.12	-.78	16.1	13.92	1.24	-.56	8.05	7.82	3.48	-.12
3000	7764	21.46	17.35	.68	-.67	10.73	10	2.36	-.34	5.37	5.44	5.72	.32
4000	10352	16.10	13.92	1.24	-.54	8.05	7.82	3.48	-.12	4.02	4.18	7.96	.76
5000	12941	12.88	11.63	1.80	-.45	6.44	6.42	4.60	.10	3.22	3.39	10.20	1.21
6000	15529	10.73	10.00	2.36	-.34	5.37	5.44	5.72	.32	2.68	2.85	12.44	1.65
7000	18117	9.20	8.77	2.92	-.23	4.60	4.73	6.84	.54	2.30	2.46	14.68	2.09
8000	20705	8.05	7.82	3.48	-.12	4.02	4.18	7.96	.76	2.01	2.17	16.92	2.53
9000	23294	7.15	7.05	4.04	-.01	3.58	3.74	9.08	.98	1.79	1.93	19.16	2.97
10,000	25882	6.44	6.42	6.42	.10	3.22	3.39	10.20	1.21	1.61	1.75	21.40	3.41

Table 3-6. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Weatherstrip; Reduce AC by 0.5 Cost of ECT, S = \$.10 /ft^2 AC = .5 Air Volume Changes/hour, Infil. Reduction

ECT Lifetime L = 12.5 years; Considered economic life = 7 years.

$i = 0.10$/year; $j = 0.14$/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	1820	9.16	8.74	.54	-.22	4.58	4.71	2.07	.55	2.29	2.45	5.14	2.1
2000	3640	4.58	4.71	2.07	.55	2.29	2.45	5.14	2.10	1.14	1.25	11.29	5.2
3000	5460	3.05	3.23	3.61	1.33	1.53	1.66	8.22	3.65	.76	.84	17.43	8.3
4000	7280	2.29	2.45	5.14	2.10	1.14	1.25	11.29	5.20	.57	.63	23.58	11.41
5000	9100	1.83	1.98	6.68	2.88	.92	1.01	14.36	6.75	.46	.51	29.72	14.51
6000	10920	1.53	1.66	8.22	3.65	.76	.84	17.43	8.30	.38	.42	35.87	17.61
7000	12740	1.31	1.43	9.75	4.43	.65	.72	20.51	9.86	.33	.36	42.01	20.71
8000	14560	1.14	1.25	11.29	5.20	.57	.63	23.58	11.41	.29	.32	48.15	23.81
9000	16380	1.02	1.12	12.83	5.98	.51	.56	26.65	12.96	.25	.28	54.30	26.91
10,000	18200	.92	1.01	14.36	6.75	.46	.51	29.72	14.51	.23	.26	60.45	30.02

Table 3-7. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Storm Window on Single Pane Window   Cost of ECT, S = \$3.00 /ft^2 R_o = .9 h-ft^2-°F/Btu

ECT Lifetime L =12.5 years; Considered economic life = 7 years. R_{ECT} = 2.0 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_s Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	14666	34.09	24.09	-.59	-.79	17.05	14.56	-.17	-.58	8.52	8.21	.65	-.17
2000	29333	17.05	14.56	-.17	-.58	8.52	8.21	.65	-.17	4.26	4.41	2.30	.67
3000	44000	11.36	10.49	.24	-.38	5.68	5.73	1.48	.25	2.84	3.01	3.95	1.50
4000	58666	8.52	8.21	.65	-.17	4.26	4.41	2.30	.67	2.13	2.29	5.60	2.33
5000	73333	6.82	6.75	1.06	.04	3.41	3.58	3.13	1.08	1.70	1.85	7.25	3.17
6000	88000	5.68	5.73	1.48	.25	2.84	3.01	3.95	1.50	1.42	1.55	8.90	4
7000	102666	4.87	4.98	1.89	.46	2.44	2.60	4.78	1.92	1.22	1.33	10.55	4.83
8000	117333	4.26	4.41	2.30	.67	2.13	2.29	5.60	2.33	1.07	1.17	12.21	5.67
9000	132000	3.79	3.95	2.71	.87	1.89	2.04	6.43	2.75	.95	1.04	13.86	6.50
10,000	146666	3.41	3.58	3.13	1.08	1.70	1.85	7.25	3.13	.85	.94	15.51	7.33

Table 3-8. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Storm Window on Double Pane Window Cost of ECT, $S = \$3.00\ /ft^2$ $R_o = 2.0\ h\text{-}ft^2\text{-}°F/Btu$

ECT Lifetime L =12.5 years; Considered economic life = 7 years. $R_{ECT} = 3.0\ h\text{-}ft^2\text{-}°F/Btu$

$i = 0.10/year$; $j = 0.14/year$

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	4000	125	50.17	-.89	-.94	62.5	35.08	-.77	-.89	31.25	22.71	-.55	-.77
2000	8000	62.5	35.08	-.77	-.89	31.25	22.71	-.55	-.77	15.63	13.59	-.10	-.55
3000	12000	41.67	27.46	-.66	-.83	20.83	16.97	-.32	-.66	10.42	9.75	.35	-.32
4000	16000	31.25	22.71	-.55	-.77	15.63	13.59	-.10	-.55	7.81	7.61	.80	-.09
5000	20000	25	19.41	-.44	-.72	12.50	11.35	.13	-.43	6.25	6.25	1.25	.14
6000	24000	20.83	16.97	-.32	-.66	10.42	9.75	.35	-.32	5.21	5.30	1.70	.36
7000	28000	17.86	15.09	-.21	-.60	8.93	8.55	.58	-.20	4.46	4.60	2.15	.59
8000	32000	15.63	13.59	-.10	-.55	7.81	7.61	.80	-.09	3.91	4.07	2.60	.82
9000	36000	13.89	12.37	.01	-.49	6.94	6.86	1.03	.02	3.47	3.64	2.05	1.05
10,000	40000	12.5	11.35	.13	-.43	6.25	6.25	1.25	.14	3.13	3.30	3.50	1.27

Table 3-9. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Insulating Thermal Curtains & Shades   Cost of ECT, S = \$ 4.5 /ft^2 R_o = .9 h-ft^2-°F/Btu

ECT Lifetime L =12.5 years; Considered economic life = 7 years. R_{ECT} = 4 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	20,666	36.29	25.11	-.61	-.8	18.15	15.28	-.22	-.61	9.07	8.67	.55	-.22
2000	41,333	18.15	15.28	-.22	-.61	9.07	8.67	.55	-.22	4.54	4.67	2.1	.57
3000	62,000	12.10	11.05	.16	-.41	6.05	6.07	1.33	.17	3.02	3.20	3.65	1.35
4000	82,666	9.07	8.67	.55	-.22	4.54	4.67	2.10	.57	2.27	2.43	5.20	2.13
5000	103,333	7.26	7.14	.94	-.02	3.63	3.80	2.88	.96	1.81	1.96	6.75	2.91
6000	124,000	6.05	6.07	1.33	.17	3.02	3.20	3.65	1.35	1.51	1.64	8.30	3.70
7000	144,666	5.18	5.28	1.71	.37	2.59	2.76	4.43	1.74	1.30	1.42	9.85	4.48
8000	165,333	4.54	4.67	2.10	.57	2.27	2.43	5.20	2.13	1.13	1.24	11.40	5.26
9000	186,000	4.03	4.19	2.49	.76	2.02	2.17	5.98	2.52	1.01	1.11	12.96	6.04
10,000	206,666	3.63	3.80	2.88	.96	1.81	1.96	6.75	2.91	.91	1	14.51	6.83

Table 3-10. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Movable Homemade Window Shutters   Cost of ECT, $S = \$1.50/ft^2$ $R_o = .9$ h-ft^2-°F/Btu

ECT Lifetime L = 7 years;   Considered economic life = 7 years. $R_{ECT} = 6$ h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_s Btu/year-ft^2	Natural Gas Heating C_H = \$0.60/therm				Heat Pump Heating (COP = 2) C_H = \$1.20/therm				Electric Resistance Heating C_H = \$2.40/therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	22666	11.03	10.23	-.36		5.51	5.58	.29		2.76	2.93	1.58	
2000	45333	5.51	5.58	.29		2.76	2.93	1.58		1.38	1.50	4.15	
3000	68000	3.68	3.84	.93		1.84	1.99	2.86		.92	1.01	6.73	
4000	90666	2.76	2.93	1.58		1.38	1.50	4.15		.69	.76	9.30	
5000	113333	2.21	2.37	2.22		1.10	1.21	5.44		.55	.61	11.88	
6000	136000	1.84	1.99	2.86		.92	1.01	6.73		.46	.51	14.45	
7000	158666	1.58	1.71	3.51		.79	.87	8.01		.39	.44	17.03	
8000	181333	1.38	1.50	4.15		.69	.76	9.30		.34	.38	19.60	
9000	204000	1.23	1.34	4.79		.61	.68	10.59		.31	.34	22.18	
10,000	22666	1.10	1.21	5.44		.55	.61	11.88		.28	.31	24.75	

Table 3-11. Technical and Economic Performance of ECT in Different Heating Climates

ECT: Insulation Decorator Shutters   Cost of ECT, S = \$ 6.00/ft^2 R_o = .9 h-ft^2-°F/Btu

ECT Lifetime L = 25 years;   Considered economic life = 7 years. R_{ECT} = 6 h-ft^2-°F/Btu

i = 0.10/year; j = 0.14/year

Heating Degree Days °F-day/year	Heat Saved Q_S Btu/year-ft^2	NATURAL GAS HEATING C_H = \$0.60/Therm				Heat Pump Heating (COP = 2) C_H = \$1.20/Therm				Electric Resistance Heating C_H = \$2.40/Therm			
		S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years	S/R years	N years	FOM L= Lifetime	FOM L= 7 years
1000	22,666	44.12	28.47	-.18	-.84	22.06	17.71	.63	-.68	11.03	10.23	2.27	-.36
2000	45,333	22.06	17.71	.63	-.68	11.03	10.23	2.27	-.36	5.51	5.58	5.54	.29
3000	68,000	14.71	12.95	1.45	-.52	7.35	7.22	3.90	-.03	3.68	3.84	8.81	.93
4000	90,666	11.03	10.23	2.27	-.36	5.51	5.58	5.54	.29	2.76	2.93	12.08	1.58
5000	113,333	8.82	8.46	3.09	-.20	4.41	4.55	7.17	.61	2.21	2.37	15.34	2.22
6000	136,000	7.35	7.22	3.90	-.03	3.68	3.84	8.81	.93	1.84	1.99	18.61	2.86
7000	158,666	6.30	6.30	4.72	.13	3.15	3.32	10.44	1.25	1.58	1.71	21.88	3.51
8000	181,333	5.51	5.58	5.54	.29	2.76	2.93	12.08	1.58	1.38	1.50	25.15	4.15
9000	204,000	4.90	5.01	6.35	.45	2.45	2.62	13.71	1.90	1.23	1.34	28.42	4.79
10,000	22,666	4.41	4.55	7.17	.61	2.21	2.37	15.34	2.22	1.10	1.21	31.69	5.44

Table 3-12. Technical and Economic Performance of ECT in Different Cooling Climates

ECT: Insulate a Bare Attic

Cost of ECT: \$.30/ft^2

ECT Lifetime L = 25 years

i = 0.10

j = 0.14

R_0 = 3 h-ft^2-°F/Btu

R_{ECT} = 22 h-ft^2-°F/Btu

Considered Economic Lifetime = 7 years

Electricity Cost = 8.2¢/kWh

Air-Conditioner COP = 2.7

Cooling Degree-Days	Heat Gain Reduction Btu/year-ft^2	Summer Money Saved by ECT, R \$/year-ft^2	S/R Years	Life Cycle Payback N Years	FOM L = Lifetime	FOM L = 7 years
1000	6909	.061	4.89	5.00	6.47	.45
1500	10,363	.092	3.26	3.43	10.1	1.18
2000	13,818	.123	2.44	2.61	13.8	1.90
2500	17,272	.153	1.96	2.11	17.4	2.63
3000	20,727	.184	1.63	1.77	21.1	3.36
3500	24.181	.214	1.40	1.52	24.8	4.08
4000	27,636	.246	1.22	1.34	28.5	4.81

Table 3-13. Technical and Economic Performance of ECT in Different Cooling Climates

ECT: Upgrade Existing Attic Insulation from R-11 to R-30

R_0 = 14 h-ft^2-°F/Btu

Cost of ECT· \$.30/ft^2

R_{ECT} = 33 h-ft^2-°F/Btu

ECT Lifetime L = 25 years

Considered Economic Lifetime = 7 years

i = 0.10

Electricity Cost = 8.2¢/kWh

j = 0.14

Air-Conditioner COP = 2.7

Cooling Degree-Days	Heat Gain Reduction Btu/year-ft^2	Summer Money Saved by ECT, R \$/year-ft^2	S/R Years	Life Cycle Payback N Years	FOM L = Lifetime	FOM L = 7 years
1000	987	.0097	34.3	24.2	.05	-.79
1500	1480	.0130	22.8	18.2	.58	-.69
2000	1974	.0181	17.1	14.6	1.11	-.59
2500	2467	.0220	13.7	12.2	1.63	-.48
3000	2961	.0260	11.4	10.5	2.16	-.38
3500	3454	.0311	9.8	9.2	2.69	-.27
4000	3948	.0350	8.6	8.2	3.21	-.17

Table 3-14. Technical and Economic Performance of ECT in Different Cooling Climates

ECT Insulation in 2 x 4 Stud Walls

Cost of ECT: $.60/ft^2

ECT Lifetime L = 25 years

i = 0.10

j = 0.14

R_0 = 4 h-ft^2-°F/Btu

R_{ECT} = 13 h-ft^2-°F/Btu

Considered Economic Lifetime = 7 years

Electricity Cost = 8.2¢/kWh

Air-Conditioner COP = 2.7

Cooling Degree-Days	Heat Gain Reduction Btu/year-ft^2	Summer Money Saved by ECT, R $/year-ft^2	S/R Years	Life Cycle Payback N Years	FOM L = Lifetime	FOM L = 7 years
1000	4153	.037	16.3	14.0	1.22	-.56
1500	6230	.056	10.8	10.1	2.32	-.35
2000	8307	.074	8.13	7.9	3.43	-.13
2500	10,384	.092	6.51	6.5	4.54	.09
3000	12,461	.111	5.42	5.5	5.65	.31
3500	14,538	.129	4.65	4.8	6.76	.53
4000	16,615	.147	4.2	4.2	7.87	.75

Table 3-15. Technical and Economic Performance of ECT in Different Cooling Climates

ECT: Weatherstrip;
Reduce Air Volume Changes by 0.5

Cost of ECT· \$.10/ft^2

AC = 0.5 House Volume Air Changes Per Hour

ECT Lifetime L = 12.5 years

Considered Economic Lifetime = 7 years

i = 0.10

Electricity Cost = 8.2¢/kWh

j = 0.14

Air-Cnditioner COP = 2.7

Cooling Degree-Days	Heat Gain Reduction Btu/year-ft^2	Summer Money Saved by ECT, R \$/year-ft^2	S/R Years	Life Cycle Payback N Years	FOM L = Lifetime	FOM L = 7 years
1000	1820	.016	6.19	6.19	1.27	.15
1500	2730	.024	4.13	4.28	2.41	.72
2000	3640	.032	3.09	3.27	3.55	1.30
2500	4550	.040	2.48	2.64	4.68	1.87
3000	5460	.049	2.06	2.22	5.82	2.44
3500	6370	.056	1.77	1.91	6.96	3.02
4000	7280	.065	1.55	1.68	8.09	3.59

Table 3-16. Economic Parameters of Retrofit Insulating a 2 x 4 Stud Wall Considering Both Winter and Summer Benefit

Winter Heating by Heat Pump (COP = 2) Electricity cost = 8.2¢/kWh (C_H = \$12.0/therm)

Summer Cooling by Air-Conditioner (COP = 2.7, EER = 9.2) Electricity cost = 8.2¢/kWh

Cost of Wall Insulation = 60¢/ft^2

Considered Economic Period = 7 year

i = 0.10

R_o = 4 h-ft^2-°F/Btu

j = 0.14

R_{ECT} = 13 h-ft^2-°F/Btu

Table gives following information in each box:

(xx):Simple Payback Period, S/R, for combined winter and summer
:Economic Figure of Merit (FOM)

Cooling Degree Days per year °F-day/year	Heating Degree Days/year °F-day/year			
	0 (Heating Not Considered)	1000	2000	3000
0 (No Cooling)		(12.04) -.41	(6.02) .18	(4.01) .77
1000	(16.3) -.56	(6.9) .025	(4.4) .62	(3.2) 1.21
1500	(10.8) -.35	(5.7) .25	(3.9) .84	(2.9) 1.43
2000	(8.13) -.13	(4.9) .46	(3.5) 1.05	(2.7) 1.64
2500	(6.51) .09	(4.2) .68	(3.1) 1.27	(2.5) 1.86
3000	(5.42) .31	(3.7) .90	(2.9) 1.49	(2.3) 2.08
3500	(4.65) .53	(3.4) 1.11	(2.6) 1.71	(2.2) 2.30
4000	(4.07) .75	(3.0) 1.33	(2.4) 1.92	(2.0) 2.52

SECTION IV

SUMMARY AND CONCLUSIONS

The technical and economic performances of the various ECTs for different heating energy costs and heating climates are considered in Table 3-1 through 3-11. The relative performance of the candidate ECTs for the case of heat pump heating (Cost of heat C_H = \$1.20/therm, at 8.2¢/kWh and COP = 2) and a moderately mild climate (2000 Degree Days of heating per year) is shown in Table 4-1. A 2000 DD/year heating climate characterizes winters in Bakersfield, Burbank, Los Angeles Airport, Pasadena, Riverside, San Fernando, Santa Monica, and Twenty-nine Palms, and so is representative of a large segment of highly populated Southern California. Table 4-1 ranks the considered ECTs according to economic attractiveness. In every case and every climate, a homeowner without attic insulation has an opportunity to make a fine investment that can be justified from economic considerations. Every house should also be well weather-stripped The other items in Table 4-1 speak for themselves. In cool areas, or areas requiring summer air conditioning, insulation of stud walls is recommended. Insulation of the floor can be a good investment if the homeowner is willing to supply the labor. Upgrading attic insulation from R-11 to R-30 is generally not justified except in cold climates or houses with electric resistance heating.

The relative ranking of ECTs remains the same regardless of the severity of the winter climate, as shown in Table 4-2. Naturally, as the climate gets colder, installation of each ECT becomes more attractive, and some ECTs that are marginal or not recommended in mild climates become attractive in cold climates, (e.g., storm windows).

Several different techniques for reducing heat loss from windows have been considered, each independent of the other. The FOMs relative to windows decrease in the case where two or more ECTs are applied to the same window. For example, if insulating shutters and double pane windows are both applied, then the economic parameters for each will be less than if each is considered independently. Generally, ECTs working in parallel have additive contributions and so can be evaluated independently, whereas ECTs working in series assume a portion of the total energy saving contribution and so attenuate the total contribution that the other ECTs could make. In the present survey, this would primarily apply to window ECTs.

Table 4-1. Relative Ranking of the Considered ECTs - Mild Winter Climate

Heat Pump Heating (COP = 2); C_H = \$1.20/therm (electricity cost = 8.2¢/kWh)

Two economic lifetimes considered: L = ECT lifetime
L = 7 years

i = 0.10, j = 0.14

Winter Heating climate = 2000 Degree Days/year (i.e., Bakersfield, Burbank, Pomona, Laguna Beach, Los Angeles Airport, Ojai, Pasadena, Redlands, Riverside, San Bernardino, San Fernando, Santa Barbara, Santa Monica Torrance, Irvine, Twentynine Palms)

RANK	ECT	N Years	FOM L= 7 Years	FOM L= ECT Lifetime	Comments
1	Insulate a Bare Attic	2.0	2.9	18.9	Always recommended
2	Weatherstrip	2.5	2.1	5.1	Always recommended
3	Homemade Insulating Shutters	2.9	1.6	1.6	Good investment but can be a daily chore
4	Insulate Floors by Homeowner	3.4	1.2	10.2	Good investment but requires a lot of work
5	Insulate Stud Walls	6.0	0.2	5.0	Good long-term investment
6	Storm Window	8.2	-0.2	0.7	Not recommended in a mild climate
7	Insulating Thermal Shades	8.7	-0.2	0.6	Not recommended in a mild climate
8	Insulating Decorator Shutters	10.2	-0.4	2.2	Not recommended in a mild climate
9	Upgrade Attic Insul. from R-11 to R-30	11.5	-0.4	1.9	Not recommended in a mild climate
10	Insulate Floors by Contractors	13.9	-0.6	1.2	Better investments available
11	Triple Pane Window	22.7	-0.8	-0.6	Not recommended

Table 4-2. Relative Ranking of the Considered ECTs - Various Winter Climates

Heat Pump Heating (COP = 2) C_H = $1.20/therm (electricity cost = 8.2¢/kWh)

Considered Economic Period = 7 years

$i = 0.10$, $j = 0.14$

Rank	Energy Conserv. Technique (ECT)	FOM for Heating Degree Days/year 1000	2000	3000	4000	5000	6000
1	Insulate Bare Attic	1.0	2.9	4.9	6.9	8.8	10.8
2	Weatherstrip	0.6	2.1	3.7	5.2	6.8	8.3
3	Homemade Insulating Shutters	0.3	1.6	2.9	4.2	5.4	6.7
4	Insulate Floors by Homeowner	0.1	1.2	2.3	3.4	4.5	5.6
5	Insulate Stud Walls	-0.4	0.2	0.8	1.4	2.0	2.5
6	Storm Windows	-0.6	-0.2	0.3	0.7	1.1	1.5
7	Insulating Thermal Shades	-0.6	-0.2	0.2	0.6	1.0	1.4
8	Decorator Insulating Shutters	-0.7	-0.4	0.0	0.3	0.6	0.9
9	Upgrade Attic Insulation from R-11 to R-30	-0.7	-0.4	-0.2	0.1	0.4	0.7
10	Insulate Floors by Contractor	-0.8	-0.6	-0.3	-0.1	0.1	0.3
11	Triple Pane Windows	-0.9	-0.8	-0.7	-0.6	-0.4	-0.3

SECTION V

REFERENCES

There are many books, reports, articles, and other sources, including several magazines, dedicated to residential energy conservation. This bibliography is not inclusive, but is representative of what is available in the field. Sources intended for technical specialists have not been included here, nor have sources relating primarily to solar energy.

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